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Considerations regarding the use of the Marine Gearbox in Gas Turbine Propulsion for Particular Ships

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Abstract. The use of the marine gearbox is very important in most propulsion systems based on gas turbines, due to the high value of the turbine speed – propeller shaft ratio. Particular ships' characteristics differ from the civilian ships with several features which gives them the ability to navigate for a long time under different conditions. As a result of this navigating conditions, the main gearing inside the gearbox will find itself under different stages of structural stress. The stages will be analyzed by using the finite element analysis. The stress degree can be minimized by carefully choosing the correct type of material for the gearing, which is in close connection with the amount of heat that is dissipated due to meshing under different conditions. The purpose of this paper is the optimization of the gearing inside the gearbox such it can suffer as small as possible structural deformations under the factors determined by the use of the gearbox under different working conditions.

Keywords: Particular ship, double helical gear, type 22 frigate, finite element analysis.

1. Introduction. Particular ships

In the following paper, due to the special characteristics of the military ships compared to civilian ships, the former will be called "particular ships".

Particular vessels are distinguished by civilian ships by several features, including the following:

a) The fineness coefficient of the block (the ratio between the hull volume and the parallelepiped volume on it) has very low values (the ship is also said to be "thin").

b) Propulsion systems sacrifice fuel economy for superior speed (mainly gas turbines are used).

c) Providing them with sensors, radar, electronic warfare (active, passive, jamming, etc.) and communication equipment at frequencies not accessible to civilian aircraft and civil aircraft.

d) The presence of ordnance (large and medium sized guns, ship-to-ship or ship-to-air missiles, artillery, force protection systems, countermeasures and heat traps) and special forces.

e) Flight deck facilities (heliports) and the ability to accommodate flight equipment (helicopters) on board and to take action in cooperation with them.

f) Autonomy that is superior to civilian vessels which can be prolonged by refueling at sea (procedure for the transfer of fuels, lubricants, water, food, equipment, spare parts, people between a tanker and the reference vessel).

Figure 1 refers to particular ships around the world.

Figure 1 Examples of particular ships around the world [1], pag. 7,8,9

2. The use of gas turbine propulsion systems on particular vessels

The gas turbines used on particular vessels are derived constructively from gas turbines used in aviation. An example of a basic model of gas turbines used aboard particular ships is listed in figure 2.

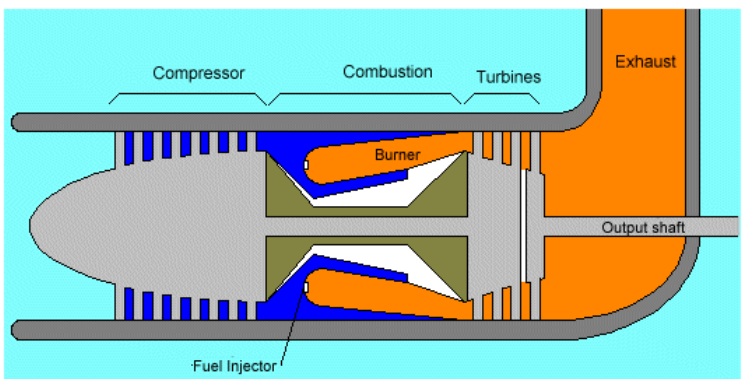

Figure 2 The schematic diagram of a naval gas turbine [2]

Particular vessels use compact forced installations with minimal operating requirements, providing them with a wide range of action and wide range of maneuverability. In addition, force installations for particular vessels require maximum economy during the normal march, the so-called economic march, as most of the march is routed by the ship with the partial load system. In this situation it is known that a very small reduction of the travel speed leads to a significant decrease in the power transmitted to the propeller. For example, when the travel speed is reduced by 30% of the maximum speed, the power delivered to the propellers decreases by 50%, and when the speed decreases by 40%, the power decreases to 25%. The high-speed march (for which the power plant needs to develop its full power) is not performed as frequently as the economic march. On particular vessels, gas turbines are used either as fork or as marching installations.

3. Common types of gears used in the maritime domain

Most main propulsion reduction gearing in nowadays' particular ships have double helical gears (fig. 3). The use of double helical gears produces a smoother action of the reduction gearing and avoids tooth shock. The purpose of positioning the teeth at complementary angles to each other (in double helical gearing) is to eliminate the end thrust, such as is developed in single helical gears.

Figure 3 Double helical gear set [3]

Helical gears can be manufactured on most modern gear cutting machines. The manufacturing process will take longer because of the relative wider face and they will be more expensive than an equivalent size spur gear. A good advantage of the helical gear compared to the spur gear is that the helical gear is capable of carrying up to 50% more load. Another advantage of the helical gear is that they make less noise, are easy to design. The main disadvantage of the helical gear is the axial thrust generated by the gears when working.

4. Main gearbox arrangement for gas turbine propulsion systems

In this paper, the research object will be the main gearbox configuration of a type 22 frigate. The gearing is made up of a main wheel and shaft, the forward end being coupled to the Oil Transfer Box whilst the after end is coupled to the forward intermediate propeller shaft. The main shaft also carries the main thrust collar.

Meshing with the main wheel are two secondary pinions, upper and lower. The secondary pinions are connected to the primary wheels by a quill shaft. The forward end of each quill shaft is connected to the pinion by a flanged coupling whilst the after end is connected to the primary wheel by a fine tooth coupling. Fitted to the forward end of the upper quill shaft, via an extension tube, is the shaft disc brake. The turning gear engages via a sliding dog clutch, into the after end of the upper quill shaft.

The primary pinion meshes with both primary wheels and forms the input member of the main gearing. Forward of the pinion is the main Gas Turbine clutch, aft of the pinion is the Cruising Turbine clutch. A schematic of the above mentioned is listed in figure 4.

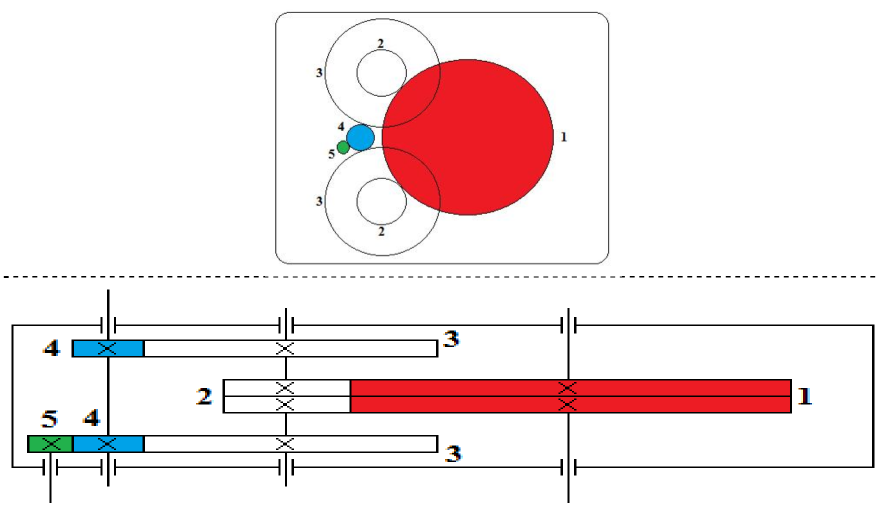

Figure 4 Main gearbox arrangement. 1-main wheel, 2-upper and lower pinions, 3-primary wheels, 4-primary pinion for the main Gas Turbine clutch, 5-primary pinion for the Cruising Turbine clutch.

5. Gear Geometric Model Parameters

For the next part of the paper, the research object will be a simple helical gear scaled model that will be analyzed using the finite element analysis. For this, the input shaft will be from the main Gas Turbine.

In the table below are described four different working conditions for the main Gas Turbine that leads to four different types of gear structural stress.

Table 1. Main Gas Turbine Parameters for different working conditions.

Working Condition	PCL [%]	Fuel Consumption $\left[\frac{l}{min}\right]$	Main shaft speed [rpm]	Throttle [%]	Oil pressure [bar]	LP Compressor speed [rpm]	Gas Turbine Exhaust Temp [^{0}C]	Power Turbine Speed [rpm]	Fuel Pressure [bar]
1	76	76,2	171	58	3,2	6100	500	3600	1,5
2	66	57,5	145	45	3,2	5600	440	3000	1,8
3	32	18,4	69	10	3,2	3000	240	1400	1,2
4	16	13,6	52	0	2,9	2000	250	1000	1,3

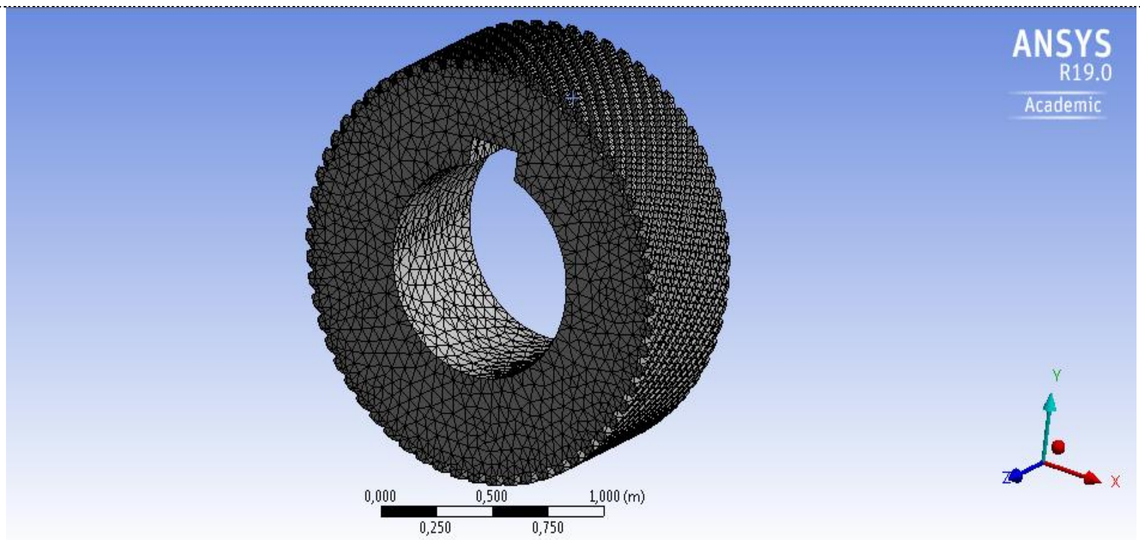

Figure 5 Simple helical gear scaled model meshed in Ansys 19 Student

The four working conditions from table 1 are commonly met among the particular ships: Marching to a Rendezvous Point, Refueling at Sea Maneuver, Helicopter Landing Maneuver respectively Berthing/Mooring Maneuver.

The PCL (Power Control Lever) establishes the amount of power used related to the maximum output power of the turbine. The main gas turbine for the 22 type frigate is a Rolls Royce Olympus TM3B, with a maximum power output of 18890,81 [KW], coupled to a main gearbox.

The moment for the input pinion is

$$M_1 = \frac{P_1}{\omega_1} \; [KNm] \tag{1}$$

The moment for the output pinion is

$$M_2 = \frac{P_2}{\omega_2} \; [KNm] \tag{2}$$

P_1 and P_2 are the output power of the main Gas Turbine, respectively the output power for the gearbox.

$$P_2 = \eta_{gearbox} P_1 \; [KW] \tag{3}$$

$$\eta_{gearbox} = 0{,}94 \ldots 0{,}98 \ [-] \tag{4}$$

$\eta_{gearbox}$ represents the output power loss due to the moving elements of the main gearbox
ω_1 and ω_2 are the angular speed for the input respectively the output pinion.

$$\omega_{1,2} = \frac{2\pi n_{1,2}}{60} \ [rpm] \tag{5}$$

n_1 and n_2 are the speeds of the input, respectively the output shaft.

For simplicity of the calculus, it is taken into account a single stage reduction.

It is known that

$$\frac{M_1}{M_2} = \frac{1}{\eta_{gearbox}} \frac{n_2}{n_1} \tag{6}$$

Therefore

$$M_2 = \eta_{gearbox} M_1 \frac{n_1}{n_2} \ [KNm] \tag{7}$$

Applying this formulae, the results for the four working conditions are showed in table 2.

Table 2. Calculation of the output moment related to the four working conditions.

Working Condition	PCL [%]	Input power P [KW]	Power Turbine Speed n_1 [rpm]	Main shaft speed n_2 [rpm]	Input moment M_1 [KNm]	Output moment M_2 [KNm]
1	76	14357,015	3600	171	38,102	754,028...786,114
2	66	12467,93	3000	145	39,706	772,228...805,089
3	32	6045,059	1400	69	41,253	786,811...820,293
4	16	3022,529	1000	52	28,877	522,019...544,232

In order to use the finite element analysis the research object will be a simple helical gear scaled and meshed in Ansys 19 Student program as in figure 5.

For the simulation in Ansys, the computer program will take into account two different types of steel commonly used for gear manufacturing shown in table 3. In table 4 there are also described the mechanical properties of the two steel types.

Table 3. Chemical composition.

Composition / Steel type	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Ti [%]	Rest [%]
30MnCrTi4	0,17 -0,23	0,17 - 0,37	0,8 - 1	≤0,035	≤0,040	1 – 1,3	0,04 – 0,1	96,925 – 97,82
20CrMnTi	0,95 – 1,05	0,15 – 0,35	0,25 – 0,45	≤0,025	≤0,025	1,4 – 1,65	0,021	96,429 – 97,229

Table 4. Mechanical Properties.		
Gear Material	30MnCrTi4	20CrMnTi
Density	7850 $\left[\frac{Kg}{m^3}\right]$	7750 $\left[\frac{Kg}{m^3}\right]$
Elastic modulus	172 [GPa]	140 [GPa]
Tensile strength	Min 1080 [MPa]	Min 520 [MPa]
Yield strength	Min 850 [MPa]	Min 415 [MPa]
Elongation	Min 10 [%]	Min 10 [%]
Coefficient of Thermal Expansion	$1{,}2 \cdot 10^{-5}$ [$^0C^{-1}$]	$1{,}7 \cdot 10^{-5}$ [$^0C^{-1}$]

6. Simulation results and conclusions

For the scale generated model of the helical gear constructed from the materials with the mechanical properties in table 4 and for the M_2 moments from table 2 applied on the helical gear in fig 5, the following results were obtained:

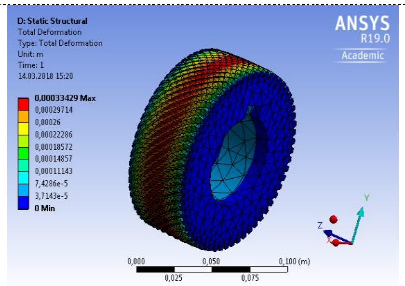

Figure 6.1

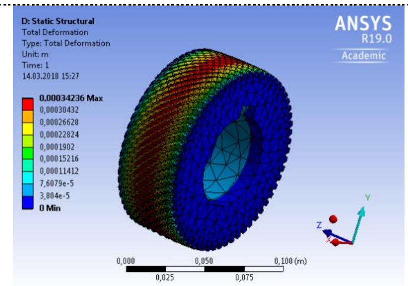

Figure 6.2

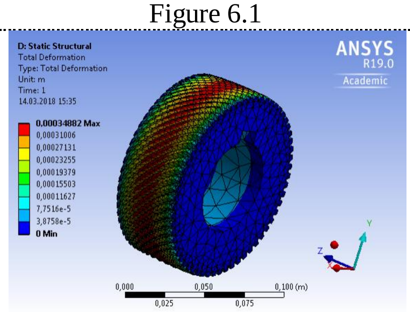

Figure 6.3

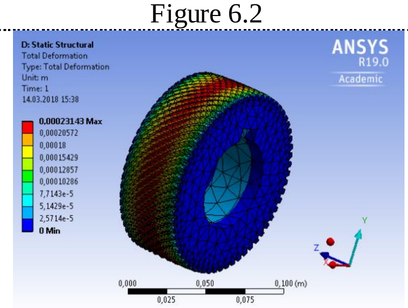

Figure 6.4

Figure 6 Simple helical gear scaled model 30MnCrTi4 meshed in Ansys 19 Student

It is obvious that the deformation pattern is identical for all four working conditions and for both gear materials. The amount with which each tooth is deformed differs with the value of the M_2 moment.

For this simulation there were used 31942 nodes and 17121 elements. The temporal factor for the simulation was 10 ms.

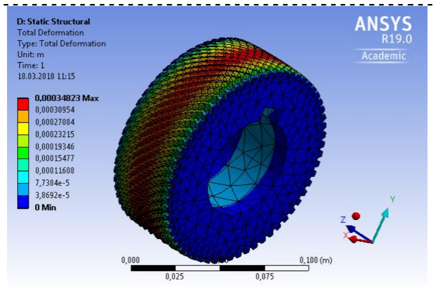

Figure 7.1

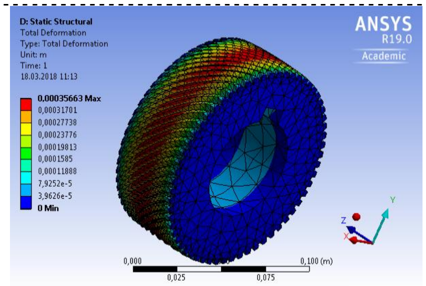

Figure 7.2

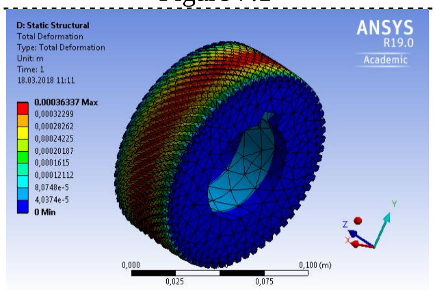

Figure 7.3

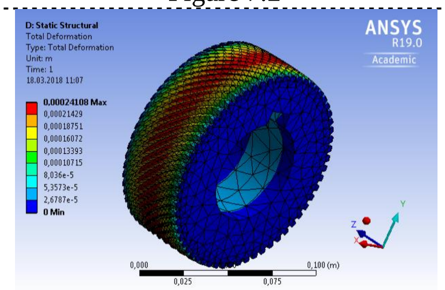

Figure 7.4

Figure 7 Simple helical gear scaled model 20CrMnTi meshed in Ansys 19 Student

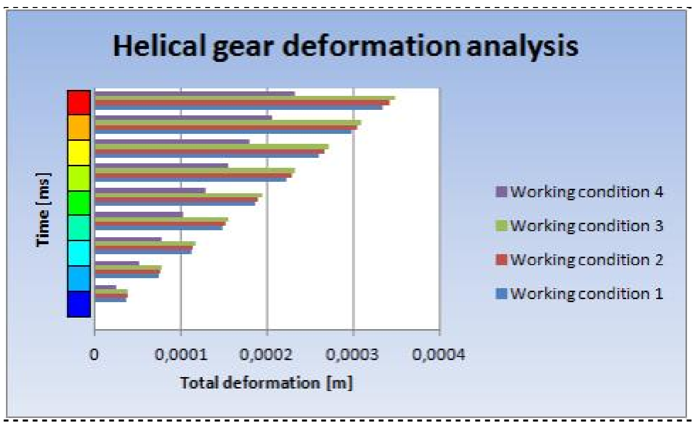

Figure 8.1 Results for 30MnCrTi4

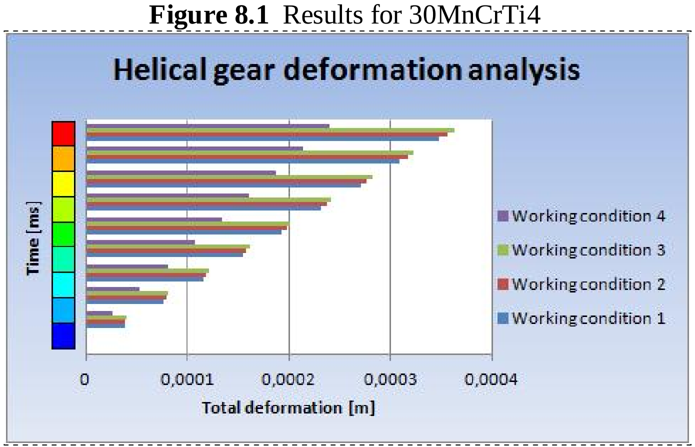

Figure 8.2 Results for 20CrMnTi

Figures 8.1 and 8.2 show that with relatively small variations in working conditions, structural deformations tend to be higher for relatively lighter working conditions.

The model which considered the choice of a simple helical gear on which it was applied the moment M_2 is closer to the real working condition. This simulation method can reduce the test cost for the real gear. The conclusions provide relevant values for the optimization of gearing in marine gearbox in gas turbine propulsion for particular ships.

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